An Algal Regenerative System for Single-Family Farms and Villages

Here's a plan that promises the development of a family living unit that embodies a maximum amount of self-sustenance and yet is in complete harmony with its external environment.

C. G. GOLUEKE
Research biologist and lecturer
Sanitary Eng. Res. Lab.
U. of Calif. Berkeley

W. J. OSWALD
Professor
Dept. Civil Engineering & School of Public Health
U. of Calif. Berkeley

INTRODUCTION

DURING THE PAST few years, considerable attention has been directed towards the development of a living unit that embodies a maximum degree of self-sustenance and be in complete harmony with its external environment. The rationale for developing such a unit is that of placing a minimum burden on the environment and on available resources, especially energy sources, through the integration of human habitation with the environment. The integration involves the development of localized systems in which residues are directly recycled into the individual living unit which generated the residues. In other words, the ideal would be a series of "closed" systems. Obviously, the systems could not be completely closed, in that energy and certain materials would have to come from outside the unit such as structural materials, utensils and certain equipment. Rather, the aim is that once a unit is set up, to make it self-sustaining.

In the course of their research on the utilization of algae for the reclamation of nutrients and water from municipal and agricultural waste waters, and on the development of photosynthetic life-support systems for extra-terrestrial applications, the authors of this paper arrived at the design of a self-contained living system which they feel merits attention. Their system, an algal regenerative system, has the advantage of providing for the utilization of solar energy. Thus, it incorporates addition as well as preservation, namely external (solar) energy is brought into the system to augment that which is conserved within the system. Bringing in external energy is essential, because short of the mythical perpetual motion machine, no system can operate without a net loss of energy. In the authors' system, solar energy supplies the energy needed to keep the system functioning, just as solar energy is the ultimate source for the earth as a whole. It has in miniature, the features of the living part of the earth as a whole, namely, photosynthesis (crop production), aerobic and anaerobic bacterial decomposition (carbon and nitrogen cycles), recycling of water, plus the use of the chemical energy of methane. The system is beyond the conceptual state because its components have been demonstrated individually and integrally by the authors as being technologically feasible in laboratory and pilot scale studies.

A description of the system is the subject of this paper. It is based upon material contained in Appendix A of the final report *Photosynthetic Reclamation of Agricultural Solid and Liquid Wastes.* (The report is being published by the U.S. Environmental Protection Administration.)

OVERALL DESCRIPTION

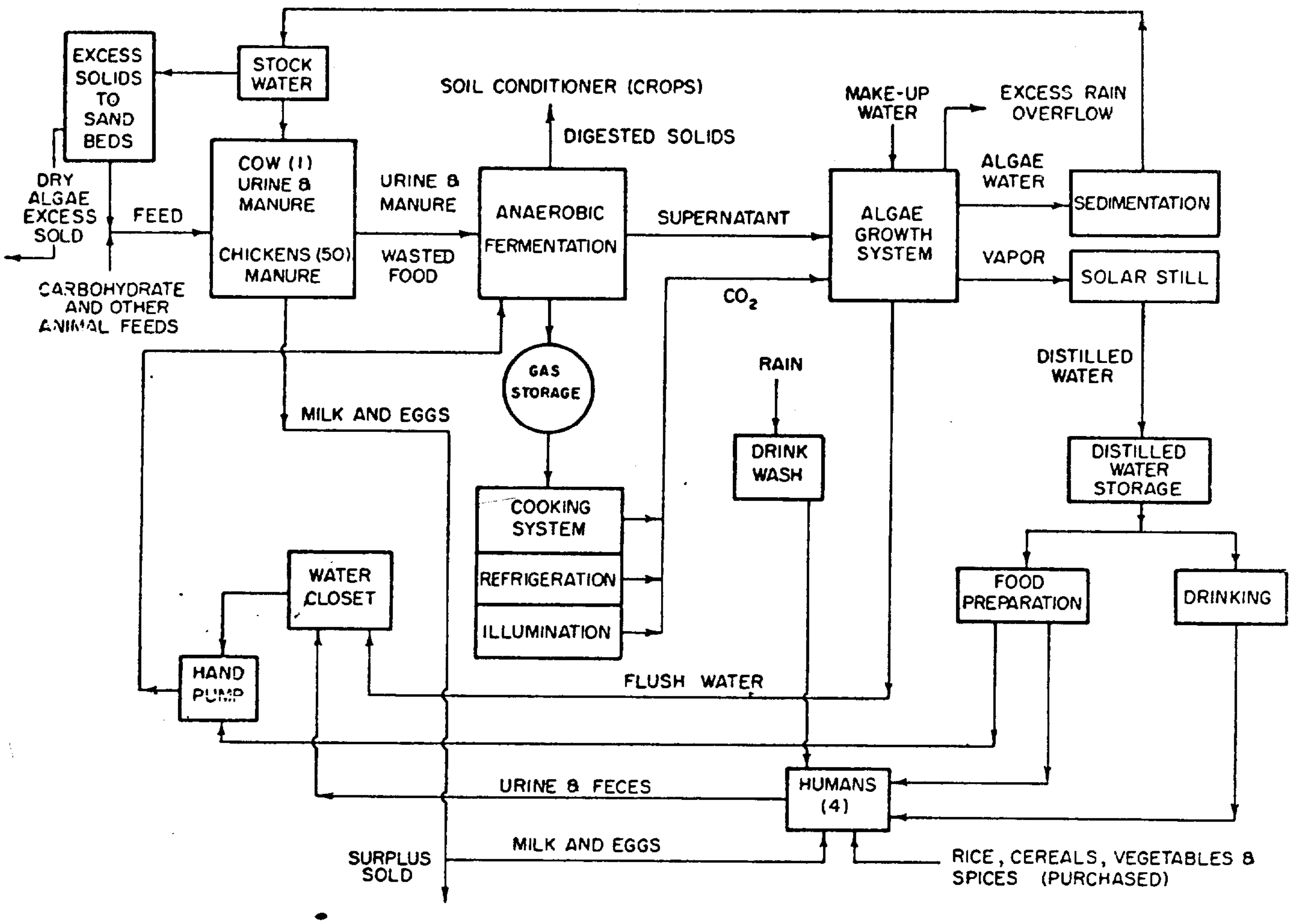
A schematic diagram of a typical small-scale algal regenerative system as envisioned by the authors is shown in Figure 1. Aside from the people and the animals, the principal components of the system are an anaerobic digester, a series of algal growth chambers, a sedimentation chamber, sand beds, a solar still, and a gas exchanger. Inasmuch as it is combined with a residence needing gas for cooking, the anaerobic digester is covered to permit combustible gas to accumulate under the cover at a pressure sufficiently above atmospheric to force the gas from the collector to the stove. Excess gas, which is rich in methane (i.e. 55 to 65%), is conveyed from the gas dome through conduits into the residence, where it is used for household purposes. Periodically, digested solids are drawn from the digester for use as soil conditioner or fertilizer in the growth of vegetables on a nearby soil plot.

At its minimum practical size, the algal regenerative system would provide waste disposal and nutrient recycle for four persons, one cow and fifty chickens. This size was arbitrarily regarded as being the most elementary that could be operated. The bases upon which the size of the components of the single-family unit were estimated, are described in the paragraphs which follow. Within as yet to be determined size limits, design data proven satisfactory for the single-family unit could be directly extrapolated to fit larger populations.

COMPONENTS OF THE SYSTEM

Digester: The size of the digestion element of the system is based upon an established microbiological minimum per capita criterion of 0.028 m^3 (1 ft^3) for humans, 0.28 m^3 (10 ft^3) for cattle, and 0.07 m^3 (0.25 ft^3) for chickens. Therefore, the minimum aggregate volumetric digester

FIGURE 1: SCHEMATIC DIAGRAM OF SINGLE-FAMILY MICROBIOLOGICAL ORGANIC WASTE RECYCLE SYSTEM

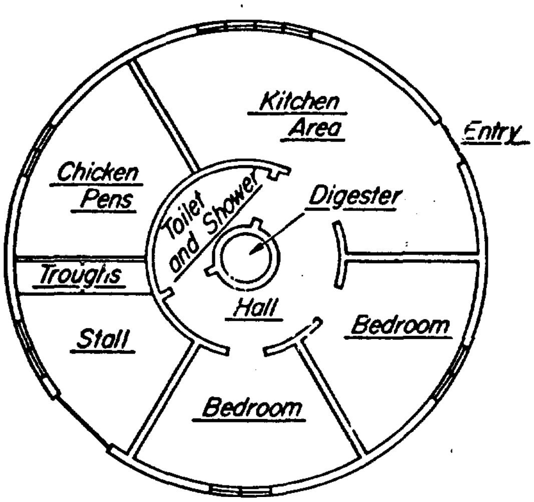


requirement for a population of four persons, fifty laying hens, and one milk cow is 0.736 m^3 (26 ft^3). However, experience has shown that to be manageable under practical conditions, the minimum size of the digester should be 1 meter in diameter and 2.5 meters deep. The active volume of such a digester would be 1.56 m^3 (55 ft^3), or almost twice the computed minimum requirement. Oversizing the digester would not be a waste, because benefits resulting from the additional volume will be a superior fermentation and an excellent gas conversion.

The digester is equipped with an inverted dome-type cover for gas pressurization. It also has a charging chute through which the manures and night soil and food and feed waste[3] are introduced into the digester culture *below* its surface. Wastes are introduced below the culture surface lest digester gas escape or oxygen enter by way of outside air. The latter could be disastrous if enough oxygen entered to result in an explosive mixture of methane and oxygen. Proper entry is assured by constructing recharge chutes with a side entrance below the water line. For most efficient use, the digester is positioned at the center of the ponding system and living area. Such an arrangement permits overflow supernatant to move directly into the pond system, and thereby conserve heat and minimize piping.

Algae Production Unit: The algae production unit is the most crucial part of the system. It is sized on the basis of the amount of waste nitrogen available from the contributing population. For example, an efficient milk cow may process 120 grams of nitrogen daily, of which 20 grams are excreted as milk, and 100 grams as feces and urine. An efficient laying hen may process 3 grams of nitrogen daily, of which 0.6 grams are excreted as eggs and 2.4 grams as feces. Thus, with one cow and fifty chickens, the nitrogen contributed in the form of wastes from the animals would be 2,220 grams (4.9 lbs) per day. Since each human excretes about 12 grams of nitrogen each day, four persons waste about 48 grams of nitrogen per day. The aggregate amount of waste nitrogen would then be 268 grams daily. Past experience has shown in an algal system based upon the use of animal manure as a nutrient source, nitrogen, phosphorus, and other elements are always in excess with respect to carbon. It also indicates that the composition of most unicellular algae grown under such conditions may be assumed to be 10% nitrogen. (Algae growing in less nitrogen rich waters usually have a nitrogen content of 6 to 8%.) Thus, if all waste nitrogen were to be recycled, the amount of algae grown each day would be 2,680 grams (5.9 lbs). If the production rate is assumed to be 0.33 grams of algae per day, the standing biomass of algae required would be 8,130 grams (18 lbs). Assuming a concentration of 500 mg per liter, the culture volume required would be 16,250 liters (4,294 gal.).

The design depth of a culture is based upon the fact that experience has shown that an adequately mixed algal culture attains a concentration which permits light to penetrate it to one-third the culture depth. Since light of daylight intensity penetrates about 12 cm into a culture having a concentration of 500 mg per liter, the depth of the culture should be 36 cm. Although the algal culture itself is only 36 cm deep, the walls of the pond structure should be 0.5 meters high so as to provide freeboard. Inasmuch as a 36-cm deep culture occupies 28 cm²/liter, the surface area requirement for a 16,250-liter culture would be 58 m³ (623.5 ft²), and a small factor of safety is provided. In summary, the dimensions of the circular pond should be 64 m² in area and 36 cm in depth. Under warm, sunny conditions, a culture of this volume and dimensions will produce between 1 and 2.5 kg dry weight of algal protein per day.



The entire pond system consists of three concentric ponds operating in series. This arrangement ensures protection against transfer to or survival of pathogens in the final pond. Moreover, the provision of three or more ponds in series guarantees an excellent degree of treatment.

A collector hopper ½ meter wide and ⅓ meter deep is installed in the outer final section of the pond system to serve as a sump in which settleable algae are collected. The settled algae make up a 2 to 3% algal slurry. Periodically, the slurry is drawn through a valve into a watering system for the cow or is discharged on sand beds for drying. A total of 8 m² of sand beds, divided into four beds of 2 m² each are required. The sand beds should be underdrained so that water can be collected and returned to the system as the need arises.

The human occupants in any system require potable water, i.e. fresh and having a low solids content. In the system as designed,' potable water is provided through the use of a 1.86 m² (20 ft²) solar distilling apparatus mounted in such a manner as to entrap vapor from the algal culture. Under the conditions to be met in the use of the system, a 1.86 m² solar still would yield about 37.85 liters (10 gallons) of distilled water per day—an amount sufficient to meet the drinking and cooking needs of four humans. During rainy periods, the solar still can be used as a catchment area for rain water to be used in lieu of distilled water. During the dry season, evaporation from the algal culture surface would be quite extensive; and on the hottest, windiest days when the ambient relative humidity is low, it could be as much as 757 liters (200 gallons) per day from the 64 square meters of pond surface. Consequently, provision must be made for a source of makeup water. Ground or surface water may be used to supply the deficit. The makeup water is used for bathing, for drinking water for the chickens (chickens are not tolerant to salt and

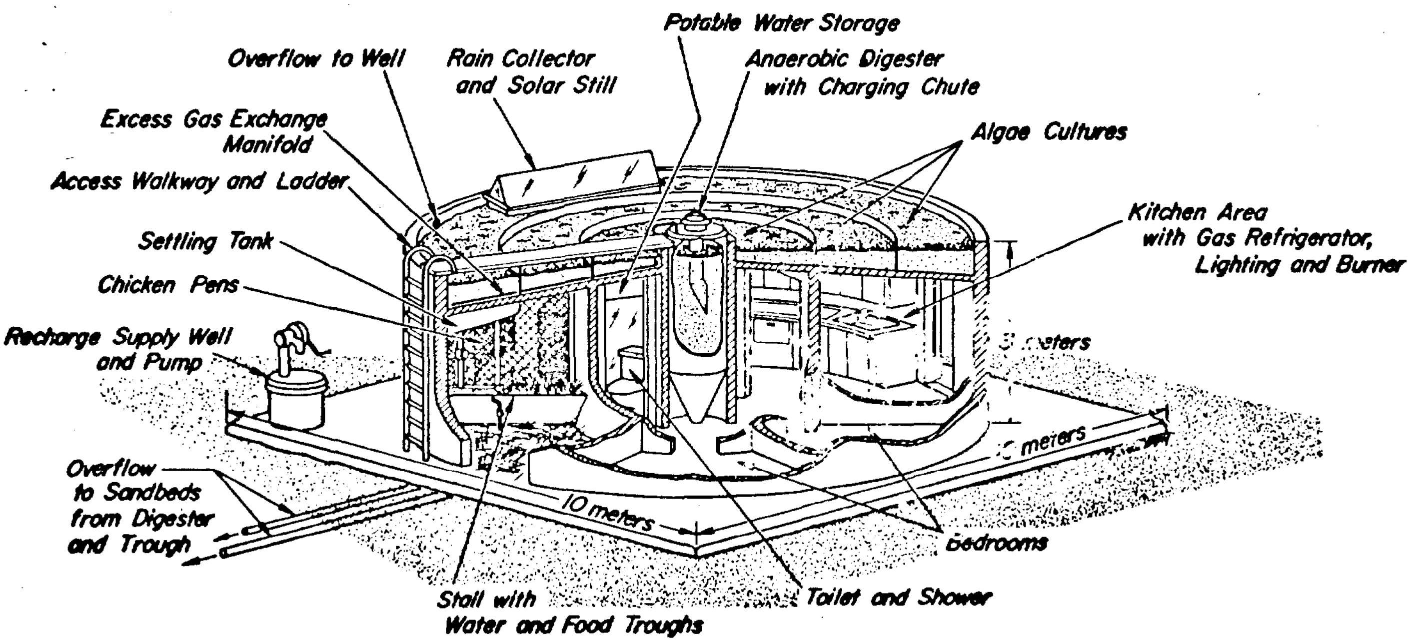


Figure 2: Schematic diagram of a dwelling unit for a family of four and their livestock which incorporates a microbiological recycle system for water, nutrients and energy in a convenient and hygienic environment.

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hence can't be given the pond water), and for cleansing purposes. The quality of this water must be carefully controlled because otherwise the chance spillage of excess water could lead to the development of unsanitary conditions. If the system were covered with transparent materials to prevent evaporation, excessive heating of the culture probably would occur. However, the possibility of utilizing the high-temperature strains of algae in a system equipped with a transparent cover should be investigated, since such a covering would reduce the need to import large amounts of water. During heavy rains, the overflow from the final pond of an open system would be suitable for disposal to surface or ground waters.

To maintain peak performance of the ponds, it is essential that they be mixed once each day. Mixing may be accomplished in myriad ways ranging from high velocity recirculation (2 ft/sec) through the use of a pump to manual stirring with brooms or paddles. In all cases, the bottom of the pond should be constructed to have sufficient strength to withstand the rigors arising from the mixing system employed. Any type of firm surface should do so long as it is not disintegrated or suspended during mixing, as would be the case if a pond has a dirt bottom. The pond floor should slope slightly outward from the center so that settled algae are moved away from the digester during mixing.

If the algal culture were placed above the house, the entire digestion and algal growth system could be located on a plot of land 10 meters by 10 meters. Supporting the algal culture above the ground, if it should prove to be feasible, would provide shelter and living space beneath it for the animals and for the humans as well.

Although from the standpoint of management, it would be economically advantageous to have larger than single-sized family units, individual units would have the advantage of enabling each family to take personal responsibility for its own system.

The Integrated System: A diagrammatic sketch of a typical family unit having the dimensions given in the preceding paragraphs and combined into a shelter complex is presented in Figure 2. The operation of the system involves the charging of all manure, urine, wasted food, night soil, and clean-up water into the digester shortly after they are produced, or at least once daily. In the digester, fermentation once established continues on a steady basis, as does gas production. Particular care would have to be exercised to avoid unnecessary loss of useful components. Therefore, all solids, liquids, and gases must be recycled or consumed. Complex substances are decomposed in the digester. Products of this decomposition are organic acids, ammonia, CO_2, and methane. The methane is stored for use as needed. The addition of the nutrients to the digester displaces soluble substances into the algal culture, where the latter serve as a substrate for algal growth. The methane, under slight pressure, is used as fuel in cooking. Carbon dioxide formed by the combustion of the methane is vented by convection to the algal culture, where a part of it is used as a carbon source by the growing algae. Algal slurry is fed to the cow and constitutes its sole course of drinking water, thereby forcing it to consume algal protein in the wet form. Algal slurry not consumed by the cow is removed from the trough and is spread over sand beds. The dewatered and dried algae can be used on the site for chicken feed or to augment the algal slurry feed for the cow, or it can be sold.

Using the space below the culture as living quarters serves to shelter both the humans and the animals from the elements. The algal culture and digester provide a buffer against rapid change in temperature for the occupants; and the metabolic heat given off by the occupants would, in turn, supply some warmth to the algal culture and digester during cool periods.

On the basis of past experience, the system, as diagrammed in Figure 2, can be expected to provide an ample and hygienic environment for a family and its essential livestock. The unit can be constructed of local materials, or perhaps can be prefabricated for import. Because it is largely powered by sunlight energy, the feasibility of such a system is greatest in tropical regions of the world, although it can be of use in other areas during the summer period.

The advantages accompanying the use of the system are: 1. the provision of a highly livable system for its occupants; 2. the establishment of an efficient and hygienic waste management; and 3. the recovery of valuable nutrients from wastes. A major disadvantage is the need for a rather substantial capital investment. However, through experimental studies with prototype units, functions and materials can be experimentally tested, and if required, modified in such a way that costs can be minimized, and operations perfected to a point at which the system would be self-supporting. If this were possible, an economic incentive would exist for investors or for governmental agencies to provide such units on a long-term loan basis. The economic basis for repayments of loans would come from maximizing the production of milk, eggs, vegetables, and algae, and minimizing the cost of essential inputs to the system such as supplementary feeds. Surplus eggs, milk, vegetables, and algae would be sold, and a portion of the money used to repay the capital investment for the system. A preliminary economic analysis indicates that a gross income of between $250 and $1,000 per year could be realized with the system. Operation costs are estimated to range from $50 to $100 per year. If only the lower income level were reached, the use of such a system probably would require a substantial subsidy. On the other hand, if the higher income level could be attained, the unit probably would be economically attractive.

AUTHORS' NOTE: The research, laboratory and pilot scale, which supplied the information used in designing the single-family algal regenerative system is reported in two publications, namely, *The Photosynthetic Reclamation of Agricultural Solid and Liquid Wastes*, Second Progress Report (SERL REPORT No. 70-1), and *The Photosynthetic Reclamation of Agricultural Solid and Liquid Wastes*, Final Report. The major part of the two reports is concerned with the development and evaluation of an integrated system of animal quarters sanitation and waste treatment and reclamation. Copies of the second progress report can be obtained from the Sanitary Engineering Research Laboratory, U. of California Richmond Field Station; 1301 S. 46th St.; Richmond, California 94804 upon payment of a $2.00 packing and mailing charge. (Checks should be made payable to the Regents of the University of California.) The number of reports available is very limited. The final report is in the process of being published by the U.S. Environmental Protection Agency. The second progress report has been summarized in the paper "Recycling System for Poultry Wastes", *Journ. Water Pollution Control Federation*, *44*(3):432-440, March 1972. (No reprints available.)